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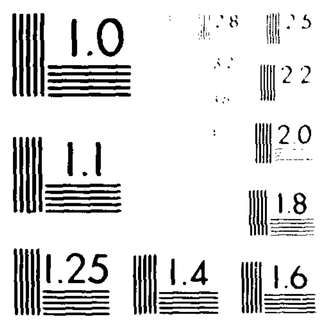

MICROCOPY RESOLUTION TEST CHART

EVALUATION OF ICE-COVERED WATER CROSSINGS (U)

JUN 1980

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Introduction

When mobility in northern regions is being considered, the need for a means to assess ice-covered water crossings becomes evident. There are two major aspects to this problem: determination of the crossing profile (from which one obtains ice thickness, support characteristics, and crack locations), and determination of the bearing capacity of the crossing. This paper discusses instrumentation developed through the U.S. Army Cold Regions Research and Engineering Laboratory to remotely measure the ice thickness and its relationship to the water body, the banks, and other ice forms. It further references applicable work done on the bearing capacity of ice sheets, and comments on the problems associated with the determination of ice strength.

Description of Instrumentation

The instrumentation used is a commercially available broad-band impulse radar system, which has been modified specifically for the remote sensing of ice thickness. The components of the system are shown in Figures 1 and 2.

The selection of the antenna (Fig. 1) determines the operating frequencies of the system. The center frequencies of the antenna range from about 100 MHz to 600 MHz, with about a 200-MHz bandwidth, and the peak radiated power varies from 2 W to 15 W. The radio frequency (RF) transmit and receive (T/R) functions are entirely within the antenna. By a sampling technique the RF is shifted down to audio

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Figure 1. Radar ice-profiling antenna attached to USCG SAR helicopter for airborne operation.

Figure 2. Components of the ice-profiling radar system (left rear control unit; right rear, analog tape recorder; foreground, graphic display unit).

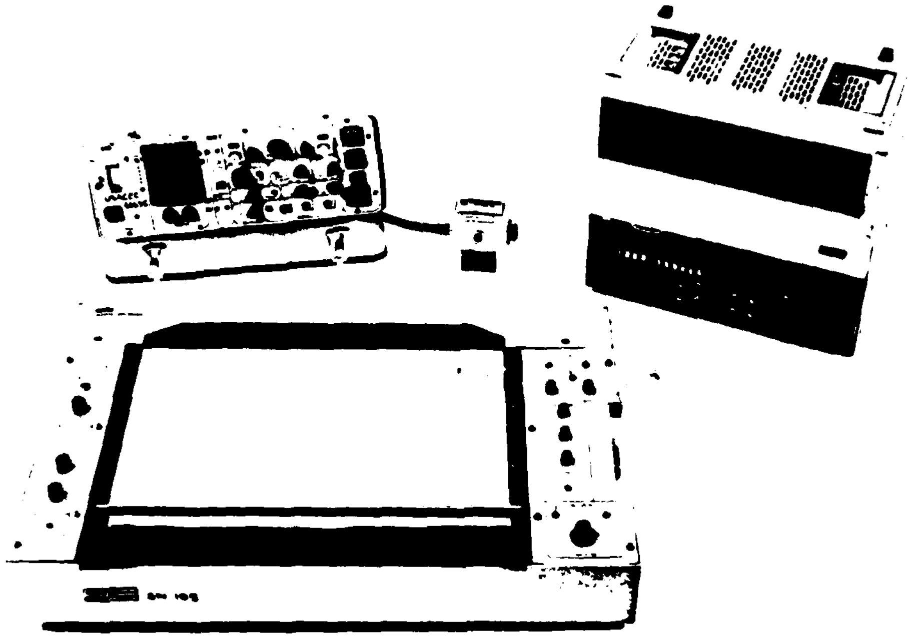

Fig 1

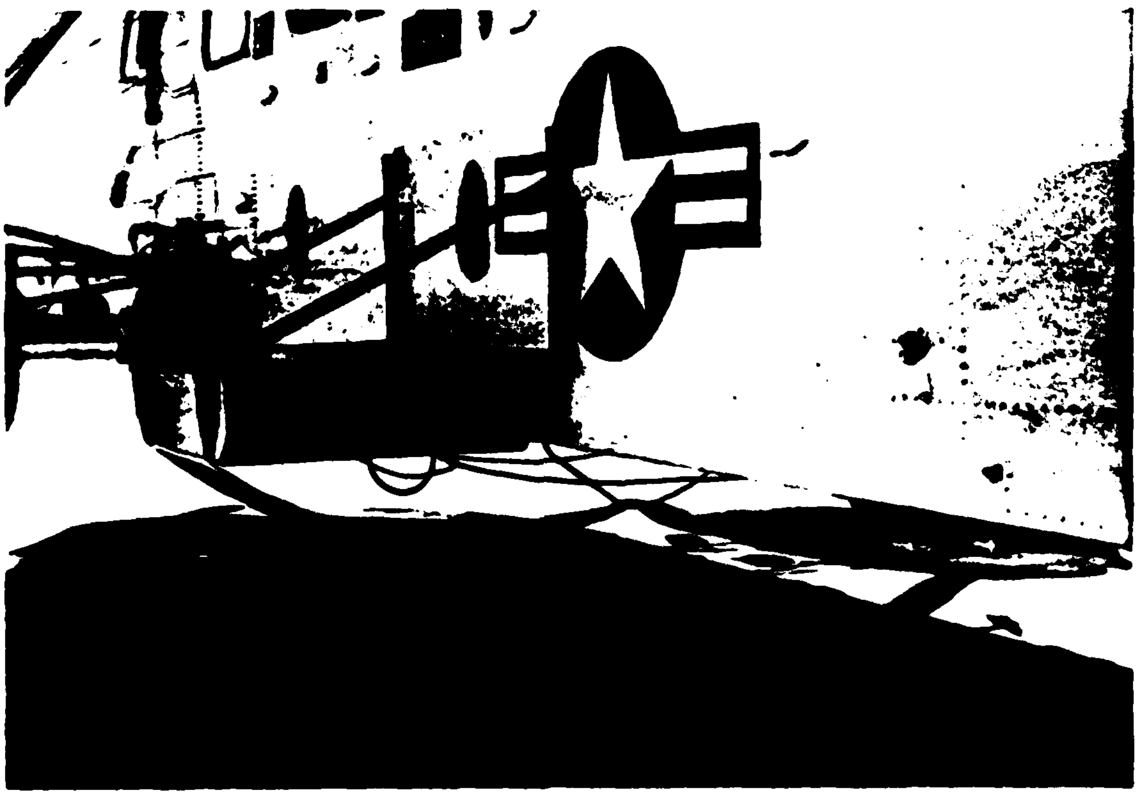

Fig 2

frequencies (AF) of 0-50 kHz to communicate with the control unit (upper left, Fig. 2) and to be compatible with the analog recorder (upper right, Fig. 2). The antenna is a center-fed, resistively loaded bow tie design.

The control unit provides control, timing, power and data manipulation. The unit allows the operator to control sample rates, recording rates, time gain, and data manipulation parameters, and to monitor the signal analog at various points throughout the system. Data manipulation is effected through an 8-bit microprocessor which implements a real-time digital filter. The characteristics of the filter are externally programmable. The microprocessor provides a precise band pass/reject function which aids noise rejection and signal enhancement. Further, a non-biasing filter prevents harmonic interference.

The analog tape recorder and the graphic unit (foreground, Fig. 2) are commercially available and standard storage and display units, respectively. The radar system transmits a broad band of energy into the medium being surveyed, and waits with an equally broad-windowed receiver for the returning signals. The signals are reflections from interfaces where the dielectric constant changes. A typical return signal on the CRT monitor (Fig. 3, left) has its counterpart on the graphic display printout (Fig. 3, right). Reflections cause signal excursions from the center region, which are depicted as sets of dark bands on the graphic. As the antenna is moved across a river section, for instance, the ice/water interface and the water/earth interface are detected and displayed as bands whose positions vary with the ice thickness and the channel configuration, respectively. The physical characteristics of the units which compose the radar system are listed in Table 1.

Table 1. Physical characteristics of the CRREL impulse radar system.

	Weight kg (lb)	Dimensions hxwxl, cm (∿ in.)
Control unit	11 (24)	18x44x39 (7x28x16)
Graphic recorder	27 (60)	12x82x53 (5x33x21)
Tape recorder	28 (62)	41x48x24 (16x19x10)
Antenna, T/R	36 (80)	34x97x94 (14x38x37)
Airborne antenna, T or R	7.5 (16.5)	27x54x90 (11x22x35)

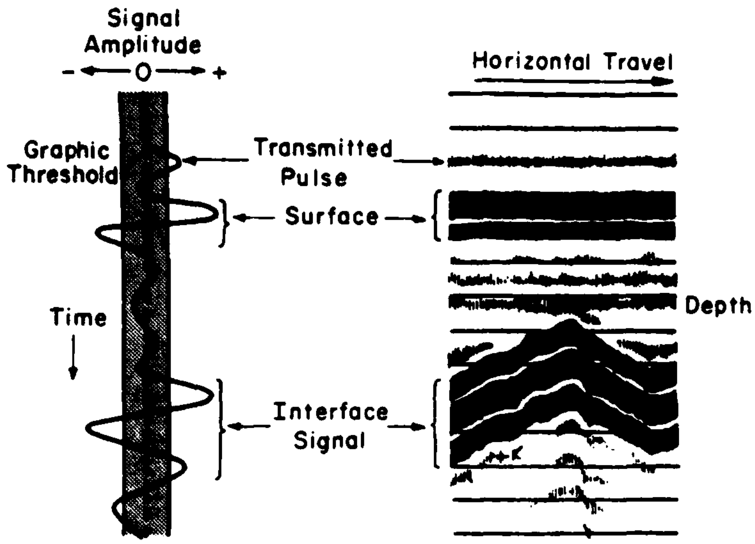

Figure 3. Ice-profiling radar system, received signal and graphic analogy.

Applications -- General

The CRREL prototype system has enjoyed a variety of applications in the last 5 years. These include both surface and air deployment. The unit has been pulled behind vehicles to measure sheet ice thickness, and flown in helicopters to measure brash and frazil accumulations, ice jams and ice runs. It has been used to profile lake bottoms and river bottoms in highly air-entrained water, and to evaluate ice bridge construction.

The airborne configuration of the system is shown in Figure 4. The helicopter positions the antenna some 4 m off the ice. When data are collected, the control unit and the tape recorder are taken to the graphic display device on the ground and a printout is made. Interpretation is made from the printout.

Figure 5 shows a transverse profile of ice accumulation due to ship traffic in the St. Marys River near Sault Ste Marie, Michigan. These data were taken in the airborne configuration and illustrate the capability of the system to be used in the airborne mode and still

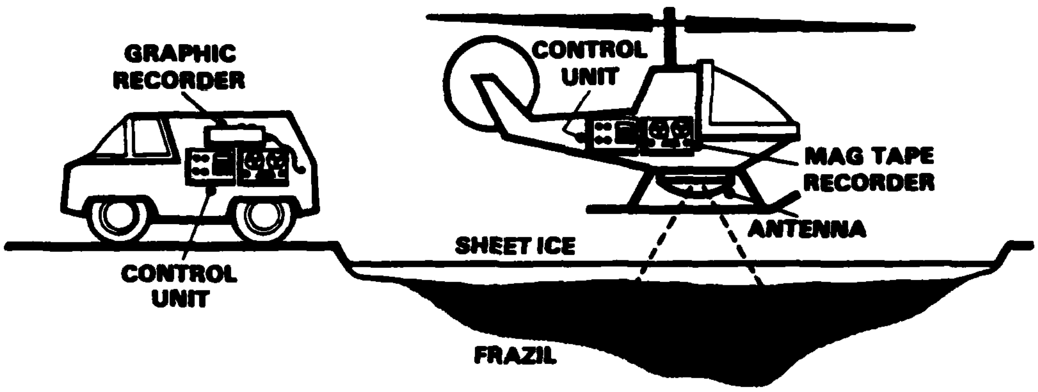

Figure 4. Airborne configuration of the ice-profiling radar system.

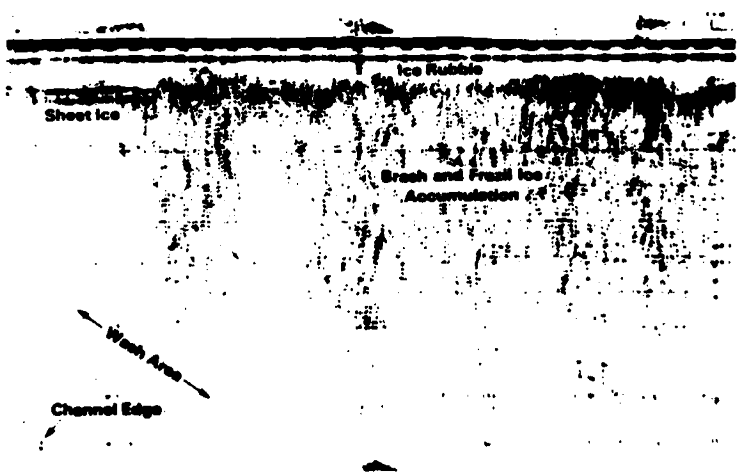

Figure 5. Graphic record of processed data representing a cross section of ice accumulation due to ship traffic in the St. Marys River.

penetrate some 3 to 5 m of 50% water and ice mixture, which is responsible for significant scattering of the transmitted signal. Figure 6 illustrates the interpretation of the data in Figure 5, and the identification of a significant factor in the accumulation of the ice, i.e. the channel edge/wash interaction which bounds the accumulation.

Application -- Ice Bridges

During the 1979 Operation Jack Frost near Fairbanks, Alaska, CRREL was asked to aid in evaluating ice bridge construction across the Tanana River. Engineer units responsible for the work were plagued with warm weather and a braided stream and had lost several pieces of equipment through the ice. At the Tanana crossings the water velocities were high and the channel variable, and the bridging was quite extensive because of the braids of the stream. The radar unit was used to obtain a continuous profile of the ice thickness on the bridges and the channel configurations. One such traverse profile of a channel crossing is shown in Figure 7. Since the sheet (bridge) thickness, the channel, the water, and frazil accumulations can be identified, a complete evaluation of the crossing can be made. A picture of this ice bridge is shown in Figure 8. Another point of interest concerns a profile taken transverse to the bridge itself, i.e. longitudinal to the channel. A significant reduction in the sheet ice thickness was found under the snow dikes on each side of the ice bridge (caused by the insulating effect of the snow bank). Such a thickness variation affects the bearing capacity of the ice bridge. Hence, as soon as bridge construction is completed the snow banks should be removed.

Advantages

The broadbanded characteristic has a specific advantage in ice/water mixtures over carrier or single-frequency radar systems. The higher frequencies in the band provide the resolution, while the lower frequencies provide the penetration into and through the water. Conventional single-frequency systems cannot have both of these characteristics.

The system is commercially available, packaged, field-worthy, and reasonably portable. The unit is not a modified laboratory unit which can be taken to the field, but a system designed for field use, and proven in the discussed applications. It can use a variety of AC or DC power sources. The implementation of the system microprocessor makes the data manipulation very flexible.

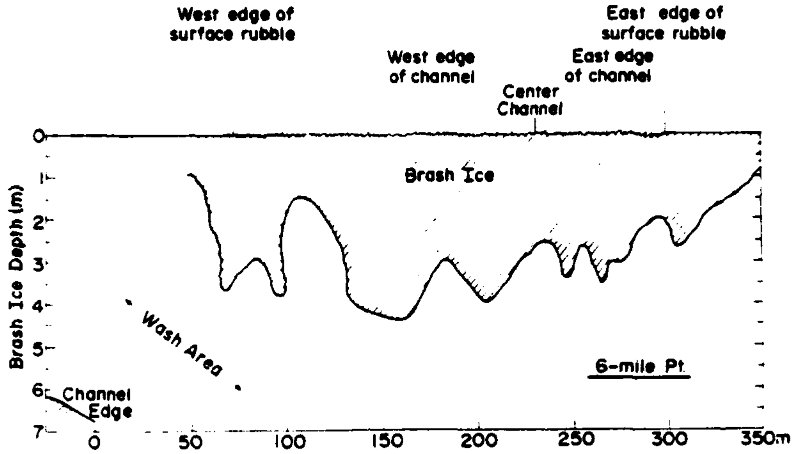

Figure 6. Sketch of the previous figure illustrating the interpretation technique.

Figure 7. Graphic record of unprocessed data representing a longitudinal profile of an ice bridge across a channel of the Tanana River, January 1979.

Fig 8

Figure 8. The ice bridge whose profile is shown in Figure 7.

Disadvantages

The major disadvantage of the system is the difficulty of interpretation. Because of this, the system is still only a research tool. For massive data processing, or for real-time data interpretation, the graphic display must be replaced, since it takes at least 16 times longer to generate the print-out as it does to acquire the data.

Since the system is broad-banded, the transmitted energy from the antenna cannot be focused as in carrier-frequency radar without an elaborate antenna array and electronics package. This requires low survey flights and an integration over an antenna footprint some 3 to 5 m in diameter for the lower frequency bands in an airborne configuration.

Although theoretically it is possible to use two antennas to make the measurement insensitive to a varying dielectric constant in the medium, this is not practical in the field with the existing equipment. Therefore, periodic ground truth data are required to assure the consistency of the dielectric constant.

Bearing Capacity of Ice Sheets

Below 0°C the bearing capacity of an ice sheet is dependent principally upon thickness, and less so upon ice type and temperature. Below -10°C the bearing capacity may be estimated as a function of thickness. The equation

$$h = 10\sqrt{P},$$

where h is ice thickness in centimeters and P is the applied load in metric tons, is a practical field relationship and gives a reasonable safety margin for single moving loads. This relationship does not apply to the bearing capacity of an ice sheet over an extended time. A number of parameter variations are tabulated in current Army publications. A more refined evaluation requires a knowledge of the ice properties and/or field testing. Selected references are given which treat these refinements.

If continued operation on the ice is considered or if ice temperatures are warm CRREL should be contacted.

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